US010238030B2

(12) **United States Patent**
Urbani

(10) **Patent No.: US 10,238,030 B2**
(45) **Date of Patent: Mar. 26, 2019**

(54) **WIRELESS MEDICAL DEVICE WITH A COMPLEMENTARY SPLIT RING RESONATOR ARRANGEMENT FOR SUPPRESSION OF ELECTROMAGNETIC INTERFERENCE**

(71) Applicant: **MEDTRONIC MINIMED, INC.**, Northridge, CA (US)

(72) Inventor: **Fabio F. Urbani**, Torrance, CA (US)

(73) Assignee: **Medtronic MiniMed, Inc.**, Northridge, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 101 days.

(21) Appl. No.: **15/371,017**

(22) Filed: **Dec. 6, 2016**

(65) **Prior Publication Data**

US 2018/0159234 A1 Jun. 7, 2018

(51) **Int. Cl.**

H01Q 9/26	(2006.01)
A01D 46/30	(2006.01)
A01D 45/26	(2006.01)

(52) **U.S. Cl.**
CPC ***A01D 46/30*** (2013.01); ***A01D 45/263*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 1/38; H01Q 7/00; H01Q 17/008; H01Q 21/28; H01Q 9/265; H01Q 1/48; H01Q 21/30; H01Q 9/26; H01P 3/08; H01L 43/00
USPC ..... 343/700 MS, 909, 893, 702
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,631,847	A	1/1972	Hobbs, II
4,212,738	A	7/1980	Henne
4,270,532	A	6/1981	Franetzki et al.
4,282,872	A	8/1981	Franetzki et al.
4,373,527	A	2/1983	Fischell

(Continued)

FOREIGN PATENT DOCUMENTS

DE	4329229	3/1995
EP	0319268	11/1988

(Continued)

OTHER PUBLICATIONS

PCT Search Report (PCT/US02/03299), dated Oct. 31, 2002, Medtronic Minimed, Inc.

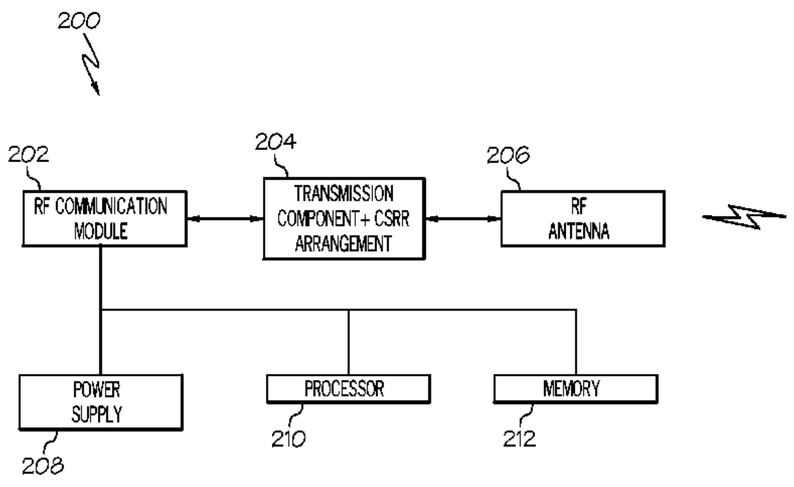
(Continued)

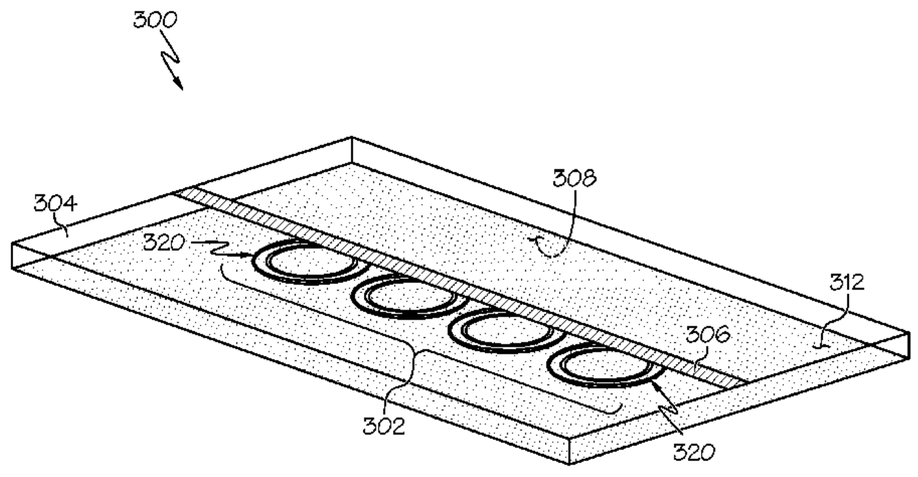
Primary Examiner — Hai V Tran
(74) *Attorney, Agent, or Firm* — Lorenz & Kopf, LLP

(57) **ABSTRACT**

A medical device as described herein includes a communication module to process radio frequency signals associated with operation of the medical device, an antenna associated with the communication module, and a microstrip transmission component coupled between the communication module and the antenna. The transmission component includes a dielectric substrate, an electrically conductive signal trace formed overlying the upper major surface of the substrate, an electrically conductive ground plane formed overlying the lower major surface of the substrate, and a complementary split ring resonator arrangement integrally formed in the ground plane, and having a layout and dimensions tuned to cause the resonator arrangement to resonate at one or more harmonic frequencies of the nominal transmission frequency of the radio frequency signals.

20 Claims, 6 Drawing Sheets





(56) **References Cited**

U.S. PATENT DOCUMENTS

4,395,259	A	7/1983	Prestele et al.
4,433,072	A	2/1984	Pusineri et al.
4,443,218	A	4/1984	Decant, Jr. et al.
4,494,950	A	1/1985	Fischell
4,542,532	A	9/1985	McQuilkin
4,550,731	A	11/1985	Batina et al.
4,559,037	A	12/1985	Franetzki et al.
4,562,751	A	1/1986	Nason et al.
4,671,288	A	6/1987	Gough
4,678,408	A	7/1987	Nason et al.
4,685,903	A	8/1987	Cable et al.
4,731,051	A	3/1988	Fischell
4,731,726	A	3/1988	Allen, III
4,781,798	A	11/1988	Gough
4,803,625	A	2/1989	Fu et al.
4,809,697	A	3/1989	Causey, III et al.
4,826,810	A	5/1989	Aoki
4,871,351	A	10/1989	Feingold
4,898,578	A	2/1990	Rubalcaba, Jr.
5,003,298	A	3/1991	Havel
5,011,468	A	4/1991	Lundquist et al.
5,019,974	A	5/1991	Beckers
5,050,612	A	9/1991	Matsumura
5,078,683	A	1/1992	Sancoff et al.
5,080,653	A	1/1992	Voss et al.
5,097,122	A	3/1992	Colman et al.
5,100,380	A	3/1992	Epstein et al.
5,101,814	A	4/1992	Palti
5,108,819	A	4/1992	Heller et al.
5,153,827	A	10/1992	Coutre et al.
5,165,407	A	11/1992	Wilson et al.
5,247,434	A	9/1993	Peterson et al.
5,262,035	A	11/1993	Gregg et al.
5,262,305	A	11/1993	Heller et al.
5,264,104	A	11/1993	Gregg et al.
5,264,105	A	11/1993	Gregg et al.
5,284,140	A	2/1994	Allen et al.
5,299,571	A	4/1994	Mastrototaro
5,307,263	A	4/1994	Brown
5,317,506	A	5/1994	Coutre et al.
5,320,725	A	6/1994	Gregg et al.
5,322,063	A	6/1994	Allen et al.
5,338,157	A	8/1994	Blomquist
5,339,821	A	8/1994	Fujimoto
5,341,291	A	8/1994	Roizen et al.
5,350,411	A	9/1994	Ryan et al.
5,356,786	A	10/1994	Heller et al.
5,357,427	A	10/1994	Langen et al.
5,368,562	A	11/1994	Blomquist et al.
5,370,622	A	12/1994	Livingston et al.
5,371,687	A	12/1994	Holmes, II et al.
5,376,070	A	12/1994	Purvis et al.
5,390,671	A	2/1995	Lord et al.
5,391,250	A	2/1995	Cheney, II et al.
5,403,700	A	4/1995	Heller et al.
5,411,647	A	5/1995	Johnson et al.
5,482,473	A	1/1996	Lord et al.
5,485,408	A	1/1996	Blomquist
5,505,709	A	4/1996	Funderburk et al.
5,497,772	A	5/1996	Schulman et al.
5,543,326	A	8/1996	Heller et al.
5,569,186	A	10/1996	Lord et al.
5,569,187	A	10/1996	Kaiser
5,573,506	A	11/1996	Vasko
5,582,593	A	12/1996	Hultman
5,586,553	A	12/1996	Halili et al.
5,593,390	A	1/1997	Castellano et al.
5,593,852	A	1/1997	Heller et al.
5,594,638	A	1/1997	Illiff
5,609,060	A	3/1997	Dent
5,626,144	A	5/1997	Tacklind et al.
5,630,710	A	5/1997	Tune et al.
5,643,212	A	7/1997	Coutre et al.
5,660,163	A	8/1997	Schulman et al.
5,660,176	A	8/1997	Iliff
5,665,065	A	9/1997	Colman et al.
5,665,222	A	9/1997	Heller et al.
5,685,844	A	11/1997	Marttila
5,687,734	A	11/1997	Dempsey et al.
5,704,366	A	1/1998	Tacklind et al.
5,750,926	A	5/1998	Schulman et al.
5,754,111	A	5/1998	Garcia
5,764,159	A	6/1998	Neftel
5,772,635	A	6/1998	Dastur et al.
5,779,665	A	7/1998	Mastrototaro et al.
5,788,669	A	8/1998	Peterson
5,791,344	A	8/1998	Schulman et al.
5,800,420	A	9/1998	Gross et al.
5,807,336	A	9/1998	Russo et al.
5,814,015	A	9/1998	Gargano et al.
5,822,715	A	10/1998	Worthington et al.
5,832,448	A	11/1998	Brown
5,840,020	A	11/1998	Heinonen et al.
5,861,018	A	1/1999	Feierbach et al.
5,868,669	A	2/1999	Iliff
5,871,465	A	2/1999	Vasko
5,879,163	A	3/1999	Brown et al.
5,885,245	A	3/1999	Lynch et al.
5,897,493	A	4/1999	Brown
5,899,855	A	5/1999	Brown
5,904,708	A	5/1999	Goedeke
5,913,310	A	6/1999	Brown
5,917,346	A	6/1999	Gord
5,918,603	A	7/1999	Brown
5,925,021	A	7/1999	Castellano et al.
5,933,136	A	8/1999	Brown
5,935,099	A	8/1999	Peterson et al.
5,940,801	A	8/1999	Brown
5,956,501	A	9/1999	Brown
5,960,403	A	9/1999	Brown
5,965,380	A	10/1999	Heller et al.
5,972,199	A	10/1999	Heller et al.
5,978,236	A	11/1999	Faberman et al.
5,997,476	A	12/1999	Brown
5,999,848	A	12/1999	Gord et al.
5,999,849	A	12/1999	Gord et al.
6,009,339	A	12/1999	Bentsen et al.
6,032,119	A	2/2000	Brown et al.
6,043,437	A	3/2000	Schulman et al.
6,081,736	A	6/2000	Colvin et al.
6,083,710	A	7/2000	Heller et al.
6,088,608	A	7/2000	Schulman et al.
6,101,478	A	8/2000	Brown
6,103,033	A	8/2000	Say et al.
6,119,028	A	9/2000	Schulman et al.
6,120,676	A	9/2000	Heller et al.
6,121,009	A	9/2000	Feller et al.
6,134,461	A	10/2000	Say et al.
6,143,164	A	11/2000	Heller et al.
6,162,611	A	12/2000	Heller et al.
6,175,752	B1	1/2001	Say et al.
6,183,412	B1	2/2001	Benkowski et al.
6,246,992	B1	6/2001	Brown
6,259,937	B1	7/2001	Schulman et al.
6,329,161	B1	12/2001	Heller et al.
6,408,330	B1	6/2002	DeLaHuerga
6,424,847	B1	7/2002	Mastrototaro et al.
6,472,122	B1	10/2002	Schulman et al.
6,484,045	B1	11/2002	Holker et al.
6,484,046	B1	11/2002	Say et al.
6,503,381	B1	1/2003	Gotoh et al.
6,514,718	B2	2/2003	Heller et al.
6,544,173	B2	4/2003	West et al.
6,553,263	B1	4/2003	Meadows et al.
6,554,798	B1	4/2003	Mann et al.
6,558,320	B1	5/2003	Causey, III et al.
6,558,351	B1	5/2003	Steil et al.
6,560,741	B1	5/2003	Gerety et al.
6,565,509	B1	5/2003	Say et al.
6,579,690	B1	6/2003	Bonnecaze et al.
6,591,125	B1	7/2003	Buse et al.
6,592,745	B1	7/2003	Feldman et al.
6,605,200	B1	8/2003	Mao et al.
6,605,201	B1	8/2003	Mao et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,607,658	B1	8/2003	Heller et al.	
6,616,819	B1	9/2003	Liamos et al.	
6,618,934	B1	9/2003	Feldman et al.	
6,623,501	B2	9/2003	Heller et al.	
6,641,533	B2	11/2003	Causey, III et al.	
6,654,625	B1	11/2003	Say et al.	
6,659,980	B2	12/2003	Moberg et al.	
6,671,554	B2	12/2003	Gibson et al.	
6,676,816	B2	1/2004	Mao et al.	
6,689,265	B2	2/2004	Heller et al.	
6,728,576	B2	4/2004	Thompson et al.	
6,733,471	B1	5/2004	Ericson et al.	
6,746,582	B2	6/2004	Heller et al.	
6,747,556	B2	6/2004	Medema et al.	
6,749,740	B2	6/2004	Liamos et al.	
6,752,787	B1	6/2004	Causey, III et al.	
6,809,653	B1	10/2004	Mann et al.	
6,881,551	B2	4/2005	Heller et al.	
6,892,085	B2	5/2005	McIvor et al.	
6,893,545	B2	5/2005	Gotoh et al.	
6,895,263	B2	5/2005	Shin et al.	
6,916,159	B2	7/2005	Rush et al.	
6,932,584	B2	8/2005	Gray et al.	
6,932,894	B2	8/2005	Mao et al.	
6,942,518	B2	9/2005	Liamos et al.	
7,153,263	B2	12/2006	Carter et al.	
7,153,289	B2	12/2006	Vasko	
7,396,330	B2	7/2008	Banet et al.	
7,522,124	B2 *	4/2009	Smith	H01Q 15/02 343/873
8,208,973	B2	6/2012	Mehta	
8,344,847	B2	1/2013	Moberg et al.	
2001/0044731	A1	11/2001	Coffman et al.	
2002/0013518	A1	1/2002	West et al.	
2002/0055857	A1	5/2002	Mault et al.	
2002/0082665	A1	6/2002	Haller et al.	
2002/0137997	A1	9/2002	Mastrototaro et al.	
2002/0161288	A1	10/2002	Shin et al.	
2003/0060765	A1	3/2003	Campbell et al.	
2003/0078560	A1	4/2003	Miller et al.	
2003/0088166	A1	5/2003	Say et al.	
2003/0144581	A1	7/2003	Conn et al.	
2003/0152823	A1	8/2003	Heller	
2003/0176183	A1	9/2003	Drucker et al.	
2003/0188427	A1	10/2003	Say et al.	
2003/0199744	A1	10/2003	Buse et al.	
2003/0208113	A1	11/2003	Mault et al.	
2003/0220552	A1	11/2003	Reghabi et al.	
2004/0061232	A1	4/2004	Shah et al.	
2004/0061234	A1	4/2004	Shah et al.	
2004/0064133	A1	4/2004	Miller et al.	
2004/0064156	A1	4/2004	Shah et al.	
2004/0073095	A1	4/2004	Causey, III et al.	
2004/0074785	A1	4/2004	Holker et al.	
2004/0093167	A1	5/2004	Braig et al.	
2004/0097796	A1	5/2004	Berman et al.	
2004/0102683	A1	5/2004	Khanuja et al.	
2004/0111017	A1	6/2004	Say et al.	
2004/0122353	A1	6/2004	Shahmirian et al.	
2004/0167465	A1	8/2004	Mihai et al.	
2004/0263354	A1	12/2004	Mann et al.	
2005/0038331	A1	2/2005	Silaski et al.	
2005/0038680	A1	2/2005	McMahon et al.	
2005/0154271	A1	7/2005	Rasdal et al.	
2005/0192557	A1	9/2005	Brauker et al.	
2006/0229694	A1	10/2006	Schulman et al.	
2006/0238333	A1	10/2006	Welch et al.	
2006/0293571	A1	12/2006	Bao et al.	
2007/0088521	A1	4/2007	Shmueli et al.	
2007/0135866	A1	6/2007	Baker et al.	
2008/0154503	A1	6/2008	Wittenber et al.	
2009/0081951	A1	3/2009	Erdmann et al.	
2009/0082635	A1	3/2009	Baldus et al.	
2014/0266974	A1 *	9/2014	Sharawi	H01Q 21/28 343/893
2015/0070228	A1 *	3/2015	Gu	H01Q 1/2283 343/727

FOREIGN PATENT DOCUMENTS

EP	0806738	11/1997
EP	0880936	12/1998
EP	1338295	8/2003
EP	1631036 A2	3/2006
GB	2218831	11/1989
WO	WO 96/20745	7/1996
WO	WO 96/36389	11/1996
WO	WO 96/37246 A1	11/1996
WO	WO 97/21456	6/1997
WO	WO 98/20439	5/1998
WO	WO 98/24358	6/1998
WO	WO 98/42407	10/1998
WO	WO 98/49659	11/1998
WO	WO 98/59487	12/1998
WO	WO 99/08183	2/1999
WO	WO 99/10801	3/1999
WO	WO 99/18532	4/1999
WO	WO 99/22236	5/1999
WO	WO 00/10628	3/2000
WO	WO 00/19887	4/2000
WO	WO 00/48112	8/2000
WO	WO 02/058537 A2	8/2002
WO	WO 03/001329	1/2003
WO	WO 03/094090	11/2003
WO	WO 2005/065538 A2	7/2005

OTHER PUBLICATIONS

(Animas Corporation, 1999). Animas . . . bringing new life to insulin therapy.

Bode B W, et al. (1996). Reduction in Severe Hypoglycemia with Long-Term Continuous Subcutaneous Insulin Infusion in Type I Diabetes. Diabetes Care, vol. 19, No. 4, 324-327.

Boland E (1998). Teens Pumping it Up! Insulin Pump Therapy Guide for Adolescents. 2nd Edition.

Brackenridge B P (1992). Carbohydrate Gram Counting a Key to Accurate Mealtime Boluses in Intensive Diabetes Therapy. Practical Diabetology, vol. 11, No. 2, pp. 22-28.

Brackenridge, B P et al. (1995). Counting Carbohydrates How to Zero in on Good Control. MiniMed Technologies Inc.

Farkas-Hirsch R et al. (1994). Continuous Subcutaneous Insulin Infusion: A Review of the Past and Its Implementation for the Future. Diabetes Spectrum From Research to Practice, vol. 7, No. 2, pp. 80-84, 136-138.

Hirsch I B et al. (1990). Intensive Insulin Therapy for Treatment of Type I Diabetes. Diabetes Care, vol. 13, No. 12, pp. 1265-1283.

Kulkarni K et al. (1999). Carbohydrate Counting a Primer for Insulin Pump Users to Zero in on Good Control. MiniMed Inc.

Marcus A O et al. (1996). Insulin Pump Therapy Acceptable Alternative to Injection Therapy. Postgraduate Medicine, vol. 99, No. 3, pp. 125-142.

Reed J et al. (1996). Voice of the Diabetic, vol. 11, No. 3, pp. 1-38.

Skyler J S (1989). Continuous Subcutaneous insulin Infusion [CSII] With External Devices: Current Status. Update in Drug Delivery Systems, Chapter 13, pp. 163-183. Futura Publishing Company.

Skyler J S et al. (1995). The Insulin Pump Therapy Book Insights from the Experts. MiniMed•Technologies.

Strowig S M (1993). Initiation and Management of Insulin Pump Therapy. The Diabetes Educator, vol. 19, No. 1, pp. 50-60.

Walsh J, et al. (1989). Pumping Insulin: The Art of Using an Insulin Pump. Published by MiniMed• Technologies.

(Intensive Diabetes Management, 1995). Insulin Infusion Pump Therapy. pp. 66-78.

Disetronic My Choice™ D-TRON™ Insulin Pump Reference Manual. (no date).

Disetronic H-TRON® plus Quick Start Manual. (no date).

(56) **References Cited**

OTHER PUBLICATIONS

Disetronic My Choice H-TRONplus Insulin Pump Reference Manual. (no date).
Disetronic H-TRON® plus Reference Manual. (no date).
(MiniMed, 1996). The MiniMed 506. 7 pages. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19961111054527/www.minimed.com/files/506_pic.htrn.
(MiniMed, 1997). MiniMed 507 Specifications. 2 pages. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19970124234841/www.minimed.com/files/mmn075.htm.
(MiniMed, 1996). FAQ: The Practical Things . . . pp. 1-4. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19961111054546/www.minimed.com/files/faq_pract.htm.
(MiniMed, 1997). Wanted: a Few Good Belt Clips! 1 page. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19970124234559/www.minimed.com/files/mmn002.htm.
(MiniMed Technologies, 1994). MiniMed 506 Insulin Pump User's Guide.
(MiniMed Technologies, 1994). MiniMed™ Dosage Calculator Initial Meal Bolus Guidelines / MiniMed™ Dosage Calculator Initial Basal Rate Guidelines Percentage Method. 4 pages.
(MiniMed, 1996). MiniMed™ 507 Insulin Pump User's Guide.
(MiniMed, 1997). MiniMed™ 507 Insulin Pump User's Guide.
(MiniMed, 1998). MiniMed 507C Insulin Pump User's Guide.
(MiniMed International, 1998). MiniMed 507C Insulin Pump for those who appreciate the difference.
(MiniMed Inc., 1999). MiniMed 508 Flipchart Guide to Insulin Pump Therapy.
(MiniMed Inc., 1999). Insulin Pump Comparison / Pump Therapy Will Change Your Life.
(MiniMed, 2000). MiniMed® 508 User's Guide.
(MiniMed Inc., 2000). MiniMed® Now [I] Can Meal Bolus Calculator / MiniMed® Now [I] Can Correction Bolus Calculator.
(MiniMed Inc., 2000). Now [I] Can MiniMed Pump Therapy.
(MiniMed Inc., 2000). Now [I] Can MiniMed Diabetes Management.
(Medtronic MiniMed, 2002). The 508 Insulin Pump A Tradition of Excellence.
(Medtronic MiniMed, 2002). Medtronic MiniMed Meal Bolus Calculator and Correction Bolus Calculator. International Version.
Abel, P., et al., "Experience with an implantable glucose sensor as a prerequiste of an artificial beta cell," Biomed. Biochim. Acta 43 (1984) 5, pp. 577-584.
Bindra, Dilbir S., et al., "Design and in Vitro Studies of a Needle-Type Glucose Sensor for a Subcutaneous Monitoring," American Chemistry Society, 1991, 63, pp. 1692-1696.
Boguslavsky, Leonid, et al., "Applications of redox polymers in biosensors," Sold State Ionics 60, 1993, pp. 189-197.
Geise, Robert J., et al., "Electropolymerized 1,3-diaminobenzene for the construction of a 1,1'-dimethylferrocene mediated glucose biosensor," Analytica Chimica Acta, 281 1993, pp. 467-473.
Gernet, S., et al., "A Planar Glucose Enzyme Electrode," Sensors and Actuators, 17, 1989, pp. 537-540.
Gernet, S., et al., "Fabrication and Characterization of a Planar Electromechanical Cell and its Application as a Glucose Sensor," Sensors and Actuators, 18, 1989, pp. 59-70.
Gorton, L., et al., "Amperometric Biosensors Based on an Apparent Direct Electron Transfer Between Electrodes and Immobilized Peroxiases," Analyst, Aug. 1991, vol. 117. pp. 1235-1241.
Gorton, L., et al., "Arnperometric Glucose Sensors Based on Immobilized Glucose-Oxidizing Enymes and Chemically Modified Electrodes," Analytica Chimica Acta. 249, 1991, pp. 43-54.
Gough, D. A., et al., "Two-Dimensional Enzyme Electrode Sensor for Glucose," Analytical Chemistry, vol. 57, No. 5, 1985, pp. 2351-2357.
Gregg, Brian A., et al., "Cross-Linked Redox Gels Containing Glucose Oxidase for Amperornetric Biosensor Applications," Analytical Chemistry, 62, pp. 258-263.
Gregg, Brian A., et al., "Redox Polymer Films Containing Enzymes. 1. A Redox-Conducting Epoxy Cement: Synthesis, Characterization, and Electrocatalytic Oxidation of Hydroquinone," The Journal of Physical Chemistry, vol. 95, No. 15, 1991, pp. 5970-5975.
Hashiguchi, Yasuhiro, MD, et al., "Development of a Miniaturized Glucose Monitoring System by Combining a Needle-Type Glucose Sensor With Microdialysis Sampling Method," Diabetes Care, vol. 17, No. 5, May 1994, pp. 387-389.
Heller, Adam, "Electrical Wring of Redox Enzymes," Acc. Chem. Res., vol. 23, No. 5, May 1990, pp. 128-134.
Jobst, Gerhard, et al., "Thin-Film Microbiosensors for Glucose-Lactate Monitoring," Analytical Chemistry, vol. 68, No. 18, Sep. 15, 1996, pp. 3173-3179.
Johnson, K.W., et al., "In vivo evaluation of an electroenzymatic glucose sensor implanted in subcutaneous tissue," Biosensors & Bioelectronics, 7, 1992, pp. 709-714.
Jönsson, G., et al. "An Electromechanical Sensor for Hydrogen Peroxide Based on Peroxidase Adsorbed on a Spectrographic Graphite Electrode," Electroanalysis, 1989, pp. 465-468.
Kanapieniene, J. J., et al., "Miniature Glucose Biosensor with Extended Linearity," Sensors and Actuators, B. 10, 1992, pp. 37-40.
Kawamori, Ryuzo, et al., "Perfect Normalization of Excessive Glucagon Responses to Intraveneous Arginine in Human Diabetes Mellitus With the Artificial Beta-Cell," Diabetes vol. 29, Sep. 1980, pp. 762-765.
Kimura, J., et al., "An Immobilized Enzyme Membrane Fabrication Method," Biosensors 4, 1988, pp. 41-52.
Koudelka, M., et al., "In-vivo Behaviour of Hypodermically Implanted Microfabricated Glucose Sensors," Biosensors & Bioelectronics 6, 1991, pp. 31-36.
Koudelka, M., et al., "Planar Amperometric Enzyme-Based Glucose Microelectrode," Sensors & Actuators, 18, 1989, pp. 157-165.
Mastrototaro, John J., et al., "An electroenzymatic glucose sensor fabricated on a flexible substrate," Sensors & Actuators, B. 5, 1991, pp. 139-144.
Mastrototaro, John J., et al., "An Electroenzymatic Sensor Capable of 72 Hour Continuous Monitoring of Subcutaneous Glucose," 14th Annual International Diabetes Federation Congress, Washington D.C., Jun. 23-28, 1991.
McKean, Brian D., et al., "A Telemetry-Instrumentation System for Chronically Implanted Glucose and Oxygen Sensors," IEEE Transactions on Biomedical Engineering, Vo. 35, No. 7. Jul. 1983, pp. 526-532.
Monroe, D.,"Novel Implantable Glucose Sensors," ACL, Dec. 1989, pp. 8-16.
Morff, Robert J. et al., "Microfabrication of Reproducible, Economical, Electroenzyrnatic Glucose Sensors," Annuaal International Conference of teh IEEE Engineering in Medicine and Biology Society, Vo. 12, No. 2, 1990, pp. 483-434.
Moussy, Francis, et al., "Performance of Subcutaneously Implanted Needle-Type Glucose Sensors Employing a Novel Trilayer Coating," Analytical Chemistry, vol. 65, No. 15, Aug. 1, 1993, pp. 2072-2077.
Nakamoto, S., et al., "A Lift-Off Method for Patterning Enzyme-Immobilized Membranes in Multi-Biosensors," Sensors and Actuators 13, 1933, pp. 165-172.
Nishida, Kenro, et al., "Clinical applications of teh wearable artifical endocrine pancreas with the newly designed needle-type glucose sensor," Elsevier Sciences B.V., 1994, pp. 353-358.
Nishida, Kenro, et al., "Development of a ferrocene-mediated needle-type glucose sensor covereed with newly designd biocompatible membrane, 2-methacryloyloxyethylphosphorylcholine-co-n-butyl nethacrylate," Medical Progress Through Technology, vol. 21, 1995, pp. 91-103.
Poitout, V., et al., "A glucose monitoring system for on line estimation oin man of blood glucose concentration using a miniaturized glucose sensor implanted in the subcutaneous tissue adn a wearable control unit," Diabetologia, vol. 36, 1991, pp. 658-663.
Reach, G., "A Method for Evaluating in vivo the Functional Characteristics of Glucose Sensors," Biosensors 2, 1986, pp. 211-220.
Shaw, G. W., et al., "In vitro testing of a simply constructed, highly stable glucose sensor suitable for implantation in diabetic patients," Biosensors & Bioelectronics 6, 1991, pp. 401-406.

(56) **References Cited**

OTHER PUBLICATIONS

Shichiri, M., "A Needle-Type Glucose Sensor—A Valuable Tool Not Only for a Self-Blood Glucose Monitoring but for a Wearable Artifiical Pancreas," Life Support Systems Proceedings, XI Annual Meeting ESAO, Alpbach-Innsbruck, Austria, Sep. 1984, pp. 7-9.
Shichiri, Motoaki, et al., "An artificial endocrine pancreas—problems awaiting solution for long-term clinical applications of a glucose sensor," Frontiers Med. Biol. Engng., 1991, vol. 3, No. 4, pp. 283-292.
Shichiri, Motoaki, et al., "Closed-Loop Glycemic Control with a Wearable Artificial Endocrine Pancreas—Variations in Daily Insulin Requirements to Glycemic Response," Diabetes, vol. 33, Dec. 1984, pp. 1200-1202.
Shichiri, Motoaki, et al., "Glycaemic Control in a Pacreatectornized Dogs with a Wearable Artificial Endocrine Pancreas," Diabetologia, vol. 24, 1983, pp. 179-184.
Shichiri, M., et al., "In Vivo Characteristics of Needle-Type Glucose Sensor—Measurements of Subcutaneous Glucose Concentrations in Human Volunteers," Hormone and Metabolic Research, Supplement Series vol. No. 20, 1988, pp. 17-20.
Shichiri, M., et al., "Membrane design for extending the long-life of an implantable glucose sensor," Diab. Nutr. Metab., vol. 2, No. 4, 1989, pp. 309-313.
Shichiri, Motoaki, et al., "Normalization of the Paradoxic Secretion of Glucagon in Diabetes Who Were Controlled by the Artificial Beta Cell," Diabetes, vol. 28, Apr. 1979, pp. 272-275.
Shichiri, Motoaki, et al., "Telemetry Glucose Monitoring Device with Needle-Type Glucose Sensor: A useful Tool for Blood Glucose Monitoring in Diabetic Individuals," Diabetes Care, vol. 9, No. 3, May-Jun. 1986, pp. 298-301.
Shichiri, Motoaki, et al., "Wearable Artificial Endocrine Pancreas with Needle-Type Glucose Sensor," The Lancet, Nov. 20, 1982, pp. 1129-1131.
Shichiri, Motoaki, et al., "The Wearable Artificial Endocrine Pancreas with a Needle-Type Glucose Sensor: Perfect Glycemic Control in Ambulatory Diabetes," Acta Paediatr Jpn 1984, vol. 26, pp. 359-370.
Shinkai, Seiji, "Molecular Recognitiion of Mono- and Disaccharides by Phenylboronic Acids in Solvent Extraction and as a Monolayer," J. Chem. Soc., Chem. Commun., 1991, pp. 1039-1041.
Shults, Mark C., "A Telemetry-Instrumentation System for Monitoring Multiple Subcutaneously Implanted Glucose Sensors," IEEE Transactions on Biomedical Engineering, vol. 41, No. 10, Oct. 1994, pp. 937-942.
Sternberg, Robert, et al., "Study and Development of Multilayer Needle-type Enzyme-based Glucose Microsensors," Biosensors, vol. 4, 1988, pp. 27-40.
Tamiya, E., et al., "Micro Glucose Sensors using Electron Mediators Immobilized on a Polypyrrole-Modified Electrode," Sensors and Actuators, vol. 18, 1989, pp. 297-307.
Tsukagoshi, Kazuhiko, et al., "Specific Complexation with Mono- and Disaccharides that can be Detected by Circular Dichroism," J. Org. Chem., vol. 56, 1991, pp. 4089-4091.
Urban, G., et al., "Miniaturized multi-enzyme biosensors integrated with pH sensors on flexible polymer carriers for in vivo applciations," Biosensors & Bioelectronics, vol. 7, 1992, pp. 733-739.
Ubran, G., et al., "Miniaturized thin-film biosensors using covalently immobilized glucose oxidase," Biosensors & Bioelectronics, vol. 6, 1991, pp. 555-562.
Velho, G., et al., "In vivo calibration of a subcutaneous glucose sensor for determination of subcutaneous glucose kinetics," Diab. Nutr. Metab., vol. 3, 1988, pp. 227-233.
Wang, Joseph, et al., "Needle-Type Dual Microsensor for the Simultaneous Monitoring of Glucose and Insulin," Analytical Chemistry, vol. 73, 2001, pp. 844-847.
Yamasaki, Yoshimitsu, et al., "Direct Measurement of Whole Blood Glucose by a Needle-Type Sensor," Clinics Chimica Acta, vol. 93, 1989, pp. 93-98.
Yokoyama, K., "Integrated Biosensor for Glucose and Galactose," Analytics Chiniica Acta, vol. 218, 1989, pp. 137-142.

* cited by examiner

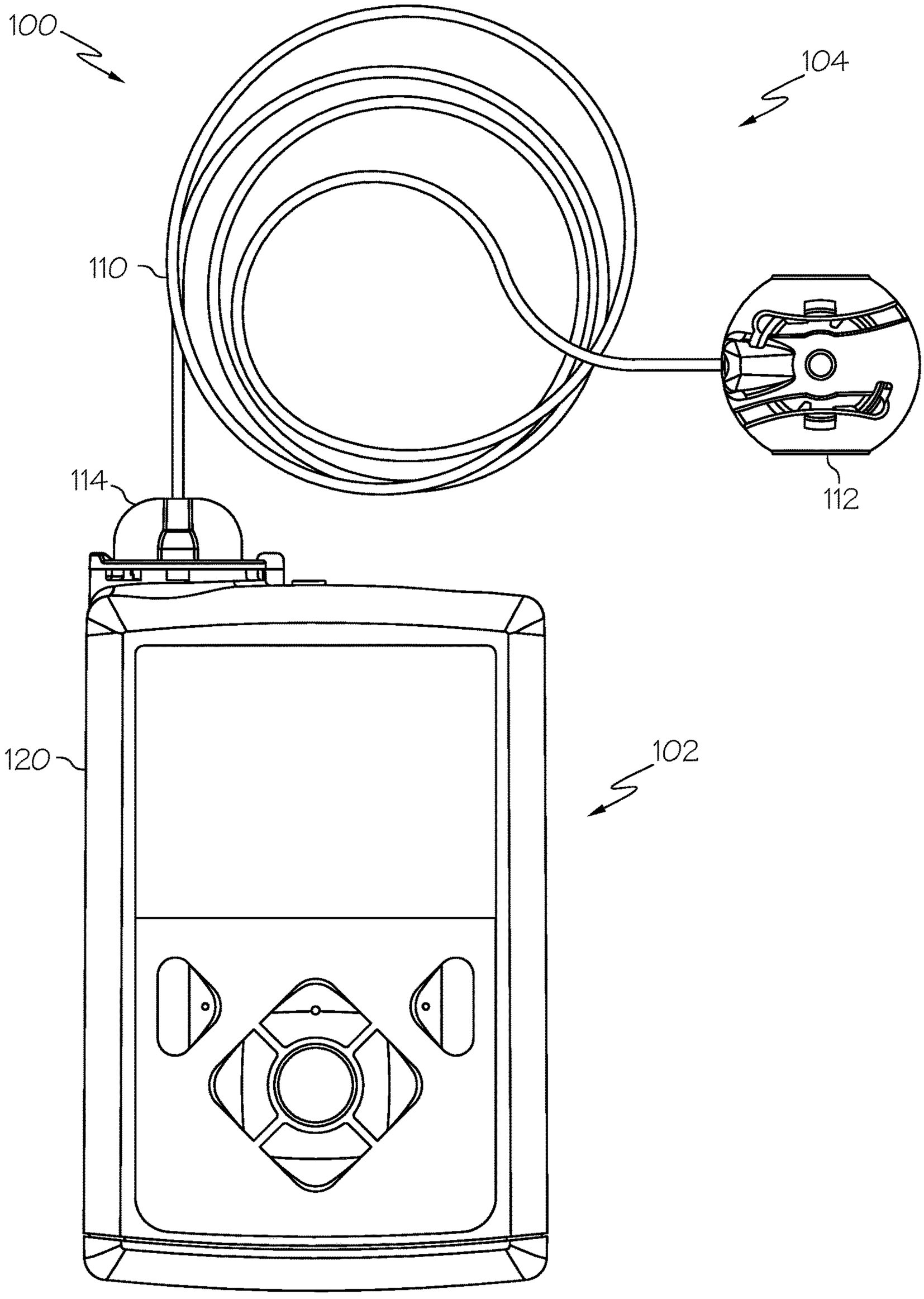


FIG. 1

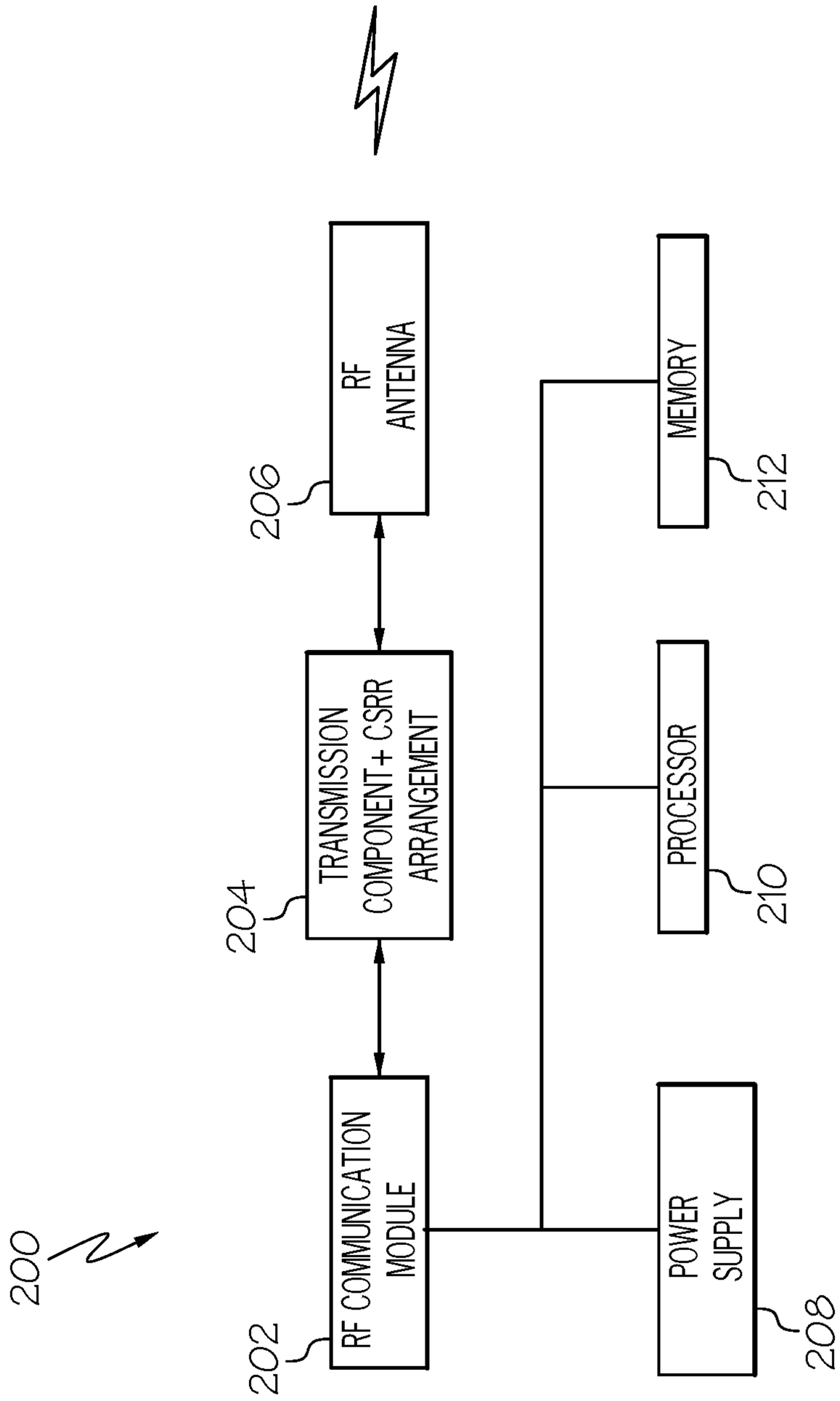

200
RF COMMUNICATION MODULE
202
TRANSMISSION COMPONENT + CSRR ARRANGEMENT
204
RF ANTENNA
206
POWER SUPPLY
208
PROCESSOR
210
MEMORY
212

FIG. 2

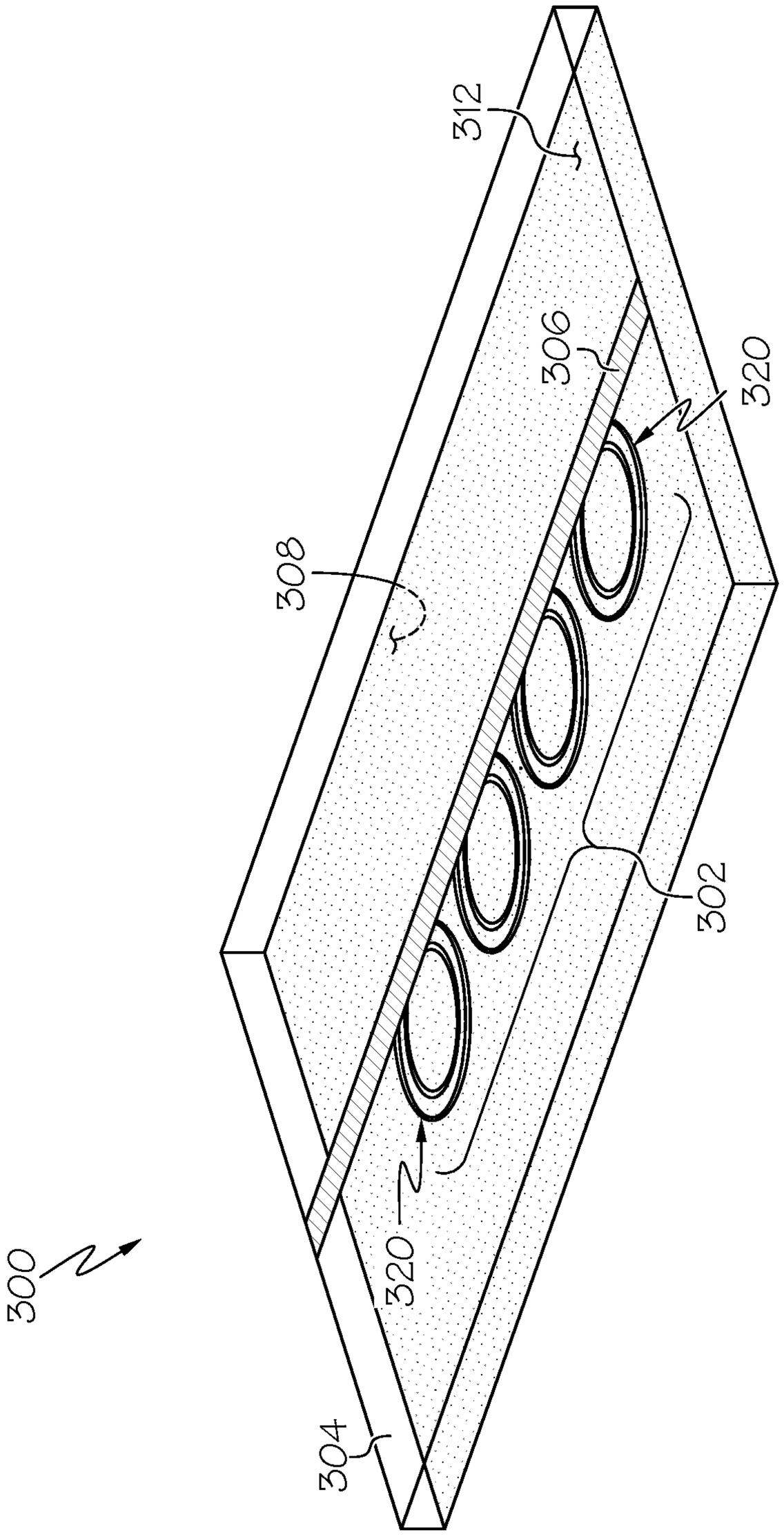


FIG. 3

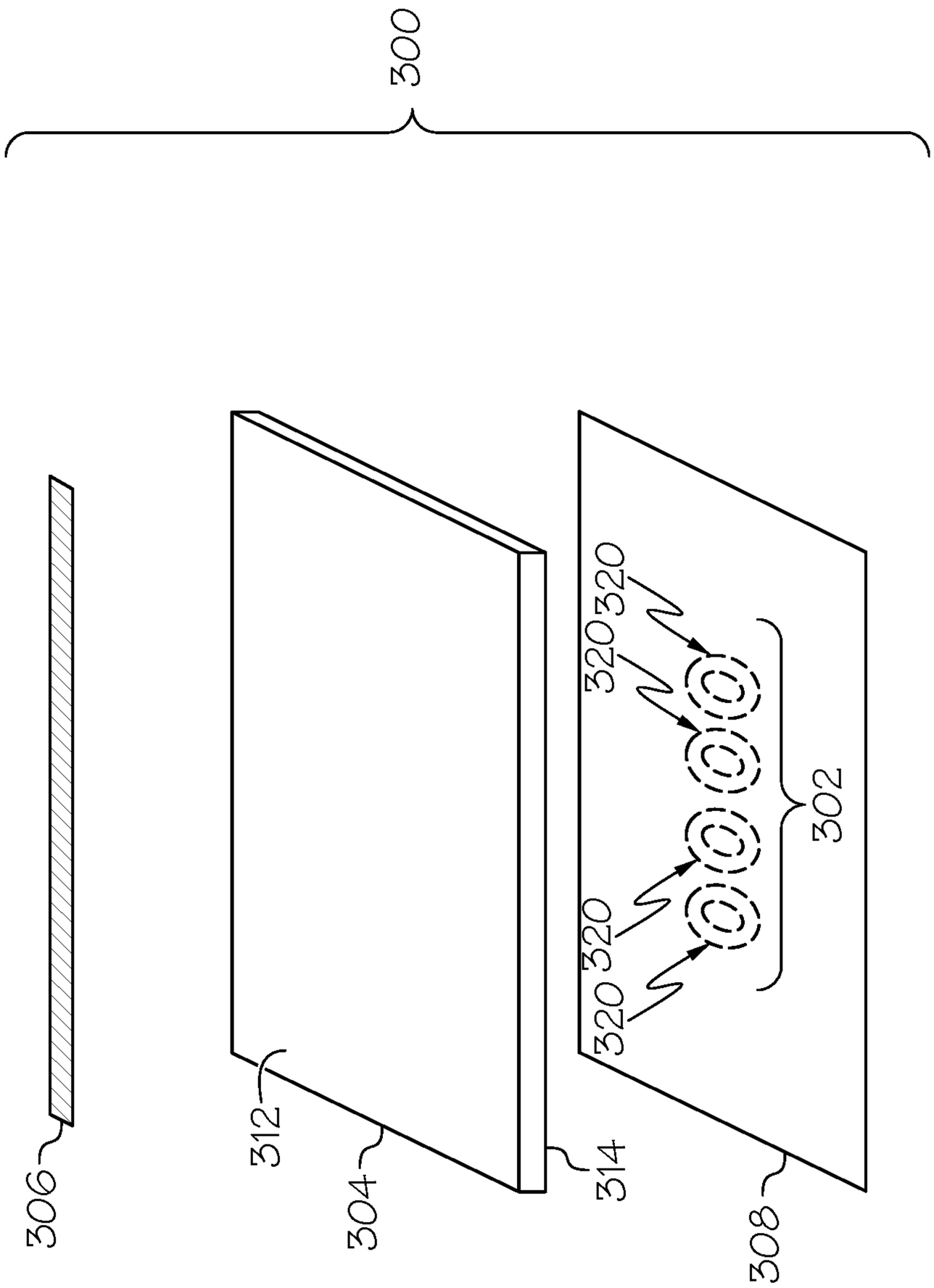


FIG. 4

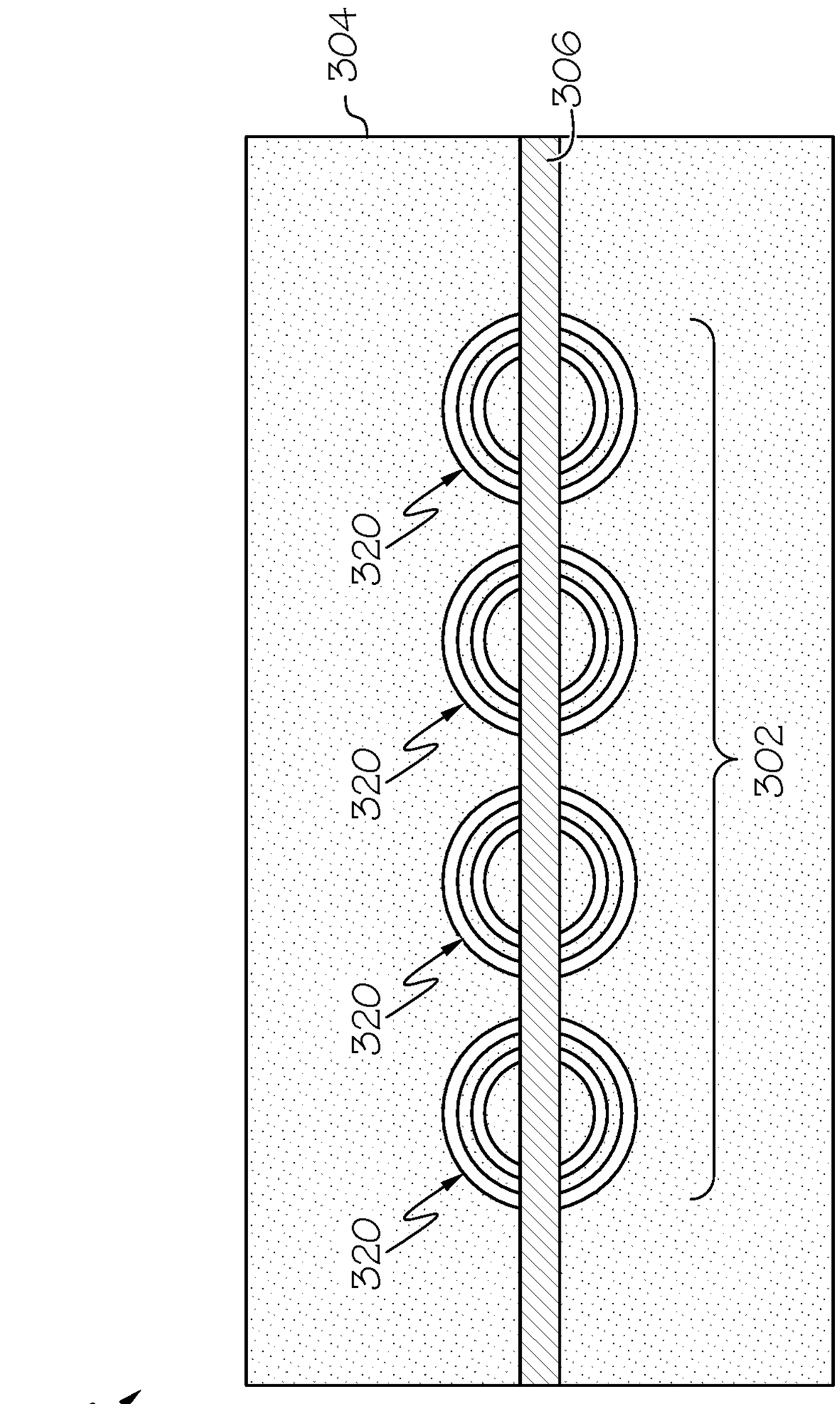


FIG. 5

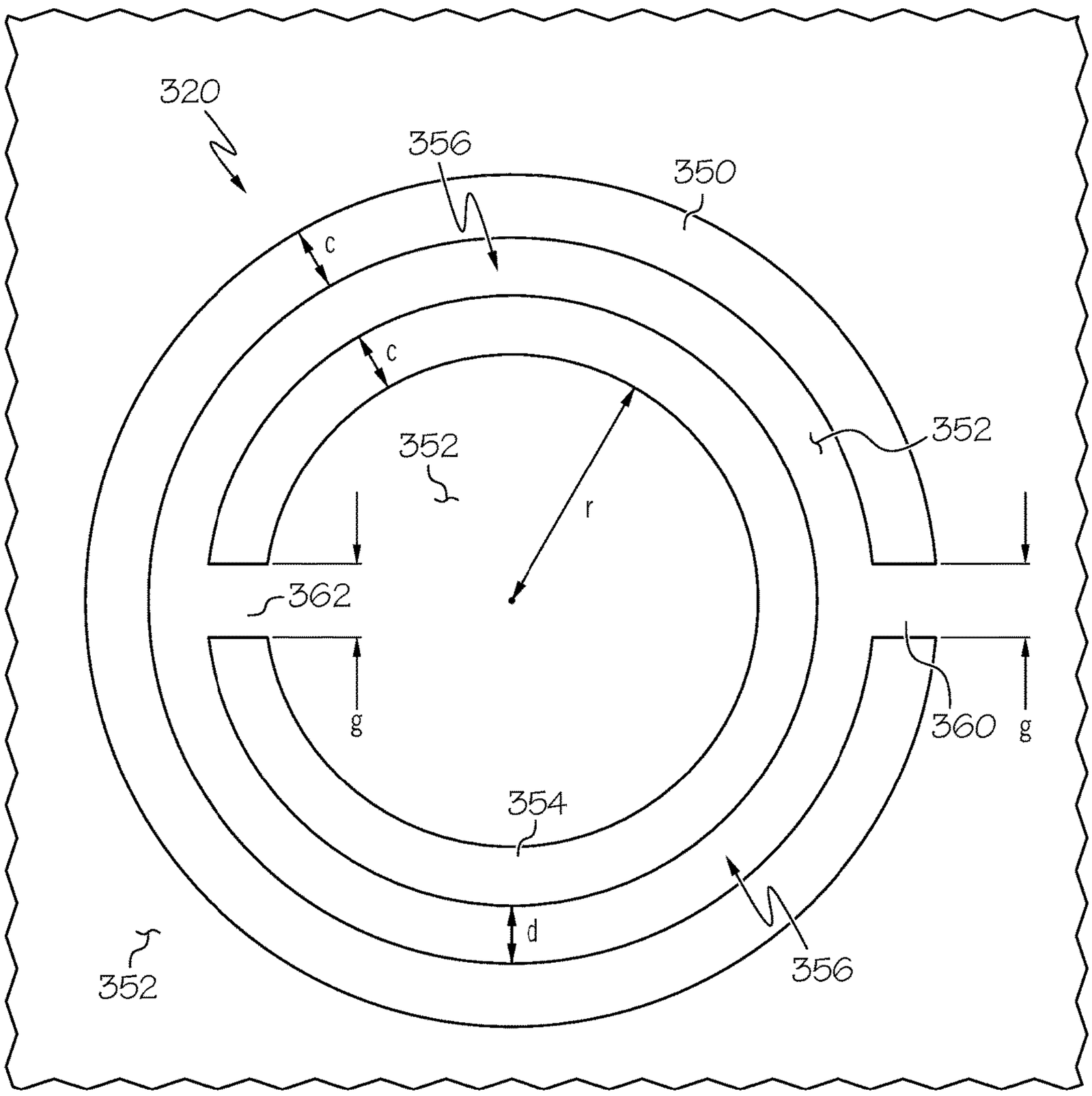


FIG. 6

WIRELESS MEDICAL DEVICE WITH A COMPLEMENTARY SPLIT RING RESONATOR ARRANGEMENT FOR SUPPRESSION OF ELECTROMAGNETIC INTERFERENCE

TECHNICAL FIELD

Embodiments of the subject matter described herein relate generally to wireless medical devices. More particularly, embodiments of the subject matter relate to techniques and components that reduce the emission of electromagnetic interference from wireless medical devices, as well as their susceptibility from unwanted electromagnetic radiation.

BACKGROUND

The prior art is replete with electronic devices that support wireless data communication. Wireless medical devices are useful for patients that have conditions that must be monitored on a continuous or frequent basis. For example, individuals with Type 1 diabetes and some individuals with Type 2 diabetes use insulin pumps to control their blood glucose levels. An insulin pump is one example of a medical fluid infusion device that can be designed to support wireless communication with other electronic devices, computer-based systems, or medical system components. For example, a wireless-enabled insulin pump can be configured to support any of the following functions: wirelessly receive control commands or instructions from another device; wirelessly transmit pump status data and/or patient data to another device; wirelessly receive glucose data from a continuous glucose sensor transmitter component; and wirelessly upload/download configuration data, updates, or settings from a server system.

Ideally, wireless medical devices should be designed to be relatively immune to electromagnetic interference and, conversely, should be designed to minimize the emission of unwanted electromagnetic radiation. In this regard, wireless devices must fulfill certain international standards and regulations related to the management of electromagnetic emissions, to ensure compatibility with neighboring electronic devices. Electromagnetic interference is a complex mechanism that takes place at different levels, including the chassis, circuit board, electronic component, and device level. Radiation sources typically include conductive trace coupling, cables attached to circuit boards, components such as chip packages and heat sinks, power busses, and other elements that can provide a low impedance current path.

Accordingly, it is desirable to have an efficient and effective approach to handle electromagnetic emission of a wireless-enabled electronic device, such as a wireless medical device. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and the foregoing technical field and background.

BRIEF SUMMARY

An exemplary embodiment of a medical device is presented here. The medical device includes a radio frequency (RF) communication module to process RF signals associated with operation of the medical device, where the RF signals have a nominal transmission frequency. The medical device also includes an RF antenna associated with the RF communication module, and a microstrip transmission component coupled between the RF communication module and the RF antenna. The microstrip transmission component includes a dielectric substrate having an upper major surface and a lower major surface opposite the upper major surface, an electrically conductive signal trace formed overlying the upper major surface, an electrically conductive ground plane formed overlying the lower major surface, and a complementary split ring resonator (CSRR) arrangement integrally formed in the electrically conductive ground plane, and having a layout and dimensions tuned to cause the CSRR arrangement to resonate at the second harmonic frequency of the nominal transmission frequency.

Another exemplary embodiment of a medical fluid infusion device is also presented here. The medical device includes an RF communication module to process RF signals associated with operation of the medical device, where the RF signals have a nominal transmission frequency. The medical device also includes an RF antenna associated with the RF communication module, and a microstrip transmission component coupled between the RF communication module and the RF antenna. The microstrip transmission component includes a dielectric substrate having an upper major surface and a lower major surface opposite the upper major surface, an electrically conductive signal trace formed overlying the upper major surface, an electrically conductive ground plane formed overlying the lower major surface, and a CSRR arrangement for the microstrip transmission component. The CSRR arrangement has a layout and dimensions tuned to cause the CSRR arrangement to suppress the second harmonic frequency component of the nominal transmission frequency of the RF signals.

Another exemplary embodiment of a medical device is also presented here. The medical device includes an RF communication module to process RF signals associated with operation of the medical device, where the RF signals have a nominal transmission frequency. The medical device also includes an RF antenna associated with the RF communication module, and a microstrip transmission component coupled between the RF communication module and the RF antenna. The microstrip transmission component includes a dielectric substrate having an upper major surface and a lower major surface opposite the upper major surface, an electrically conductive signal trace formed on the upper major surface, and a layer of electrically conductive material formed on the lower major surface. The layer of electrically conductive material includes voids formed therein to define a CSRR arrangement having a layout and dimensions tuned to cause the CSRR arrangement to resonate at the second harmonic frequency of the nominal transmission frequency.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the subject matter may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures. The drawings are not to scale, and the dimensions of certain features have been exaggerated for clarity and ease of description.

FIG. **1** is a plan view of an exemplary embodiment of a fluid delivery system that includes a medical fluid infusion device and an infusion set;

FIG. **2** is a schematic block diagram representation of a wireless communication subsystem suitable for use with the medical fluid infusion device shown in FIG. **1**;

FIG. **3** is a perspective phantom view of a microstrip transmission component having a complementary split ring resonator (CSRR) arrangement integrally formed therein;

FIG. **4** is an exploded perspective view of the microstrip transmission component shown in FIG. **3**;

FIG. **5** is a top phantom view of the microstrip transmission component shown in FIG. **3**; and

FIG. **6** is a plan view of an exemplary embodiment of a CSRR element suitable for use with the microstrip transmission component shown in FIG. **3**.

DETAILED DESCRIPTION

The following detailed description is merely illustrative in nature and is not intended to limit the embodiments of the subject matter or the application and uses of such embodiments. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Any implementation described herein as exemplary is not necessarily to be construed as preferred or advantageous over other implementations. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

Certain terminology may be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as "upper", "lower", "above", and "below" refer to directions in the drawings to which reference is made. Terms such as "front", "back", "rear", "side", "outboard," and "inboard" describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import. Similarly, the terms "first", "second" and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

The subject matter described here generally relates to the management of electromagnetic interference associated with the operation of wireless electronic devices, such as wireless medical devices. The solution presented here can be applied to any medical device using wireless communication that requires immunity and low emission of electromagnetic radiation (e.g., a defibrillator device, a pacemaker device, or the like). Although the subject matter described here can be implemented in a variety of different wireless devices, the exemplary embodiment presented here is a wireless medical fluid infusion device of the type used to treat a medical condition of a patient. The medical fluid infusion device is used for infusing a medication fluid into the body of a user. The non-limiting example described below relates to a medical device used to treat diabetes (more specifically, an insulin infusion pump), although embodiments of the disclosed subject matter are not so limited. Accordingly, the medication fluid is insulin in certain embodiments. In alternative embodiments, however, many other fluids may be administered through infusion such as, but not limited to, disease treatments, drugs to treat pulmonary hypertension, iron chelation drugs, pain medications, anti-cancer treatments, medications, vitamins, hormones, or the like.

For the sake of brevity, conventional features and functionality related to infusion systems, insulin pumps, and their wireless communication capabilities may not be described in detail here. Examples of fluid infusion pumps having wireless features may be of the type described in, but not limited to, U.S. Pat. Nos. 8,208,973 and 8,344,847, which are herein incorporated by reference.

Referring to the drawings, FIG. **1** is a plan view of an exemplary embodiment of a fluid delivery system **100** that includes a portable medical fluid infusion device **102** and a fluid conduit assembly that takes the form of an infusion set **104**. For this particular embodiment, the infusion set **104** can be coupled to the fluid infusion device **102** as depicted in FIG. **1**. The fluid infusion device **102** accommodates a fluid reservoir (hidden from view in FIG. **1**) for the medication fluid to be delivered to the user.

The illustrated embodiment of the infusion set **104** includes, without limitation: a length of tubing **110**; an infusion unit **112** coupled to the distal end of the tubing **110**; and a connector **114** coupled to the proximal end of the tubing **110**. The fluid infusion device **102** is designed to be carried or worn by the patient, and the infusion set **104** terminates at the infusion unit **112** such that the fluid infusion device **102** can deliver fluid to the body of the patient via the tubing **110**. The infusion unit **112** includes a cannula (hidden from view in FIG. **1**) that is coupled to the distal end of the tubing **110**. The cannula is inserted into the skin and is held in place during use of the fluid infusion device **102**.

The infusion set **104** defines a fluid flow path that fluidly couples the fluid reservoir to the infusion unit **112**. The connector **114** mates with and couples to a section of the fluid reservoir, which in turn is coupled to a housing **120** of the fluid infusion device **102**. The connector **114** establishes the fluid path from the fluid reservoir to the tubing **110**. Actuation of the fluid infusion device **102** causes the medication fluid to be expelled from the fluid reservoir, through the infusion set **104**, and into the body of the patient via the infusion unit **112** and cannula at the distal end of the tubing **110**. Accordingly, when the connector **114** is installed as depicted in FIG. **1**, the tubing **110** extends from the fluid infusion device **102** to the infusion unit **112**, which in turn provides a fluid pathway to the body of the patient.

The fluid infusion device **102** includes a radio frequency (RF) antenna to support wireless data communication with other devices, systems, and/or components. The RF antenna can be located inside the housing **120** or it can be integrally formed with the housing **120**. Accordingly, the RF antenna is hidden from view in FIG. **1**.

FIG. **2** is a schematic block diagram representation of a wireless communication subsystem **200** suitable for use with the medical fluid infusion device **102** shown in FIG. **1**. It should be apparent that FIG. **2** depicts the wireless communication subsystem **200** in a very simplified manner, and that a practical embodiment of the fluid infusion device **102** will of course include many additional features and components. The wireless communication subsystem **200** generally includes, without limitation: an RF communication module **202**; a transmission component **204**; an RF antenna **206** coupled to the RF communication module **202** by way of the transmission component **204**; a power supply **208**; a processor **210**; and an appropriate amount of memory **212**. As explained in more detail below, an exemplary embodiment of the transmission component **204** includes a complementary split ring resonator (CSRR) arrangement incorporated

therein. The various operating elements of the wireless communication subsystem **200** are coupled together as needed to facilitate the delivery of operating power from the power supply **208**, the transfer of data, the transfer of control signals and commands, and the like.

The RF communication module **202** is suitably configured to process RF signals associated with the operation of the fluid infusion device **102**, and to otherwise support the wireless communication functions of the fluid infusion device **102**. In this regard, the RF communication module **202** may include a transceiver or radio element that generates RF signals suitable for transmission, and that is capable of receiving RF signals generated by neighboring devices, systems, or components. Thus, the RF communication module **202** is suitably configured to generate the RF signals to be transmitted by the antenna **206**. For the exemplary embodiment described herein, the RF communication module **202** is designed to operate in the ultra-high frequency (UHF) band. Alternate embodiments may instead utilize other RF bands or frequencies as appropriate. In certain practical embodiments, the RF communication module **202** and the RF antenna are designed and tuned to accommodate RF signals having a nominal transmission frequency centered around 2.4 GHz. In this regard, the RF communication module **202** and the RF antenna **206** can be suitably configured to handle RF signals having frequencies within the range of about 2.402 GHz to about 2.480 GHz.

The RF antenna **206** is operationally associated with the RF communication module **202**. Thus, the RF antenna **206** can be designed, configured, and tuned to accommodate the particular operating frequency band utilized by the RF communication module **202**. The RF antenna **206** is suitably configured to transmit and receive RF energy associated with the operation of the host electronic device. Accordingly, the transmission component **204** is coupled between the RF communication module **202** and the RF antenna **206** to convey RF signals in a bidirectional manner. As described in more detail below, the transmission component **204** can be realized as a microstrip transmission line having an electrically conductive signal trace fabricated on the upper surface of a dielectric substrate, and having an electrically conductive ground plane fabricated on the lower surface of the dielectric substrate. Moreover, the wireless communication subsystem **200** includes a CSRR arrangement that is preferably realized as an integrated feature of the transmission component **204**.

The power supply **208** may be a disposable or rechargeable battery, a set of batteries, or a battery pack that is rated to provide the necessary voltage and energy to support the operation of the wireless communication subsystem **200**. Alternatively or additionally, the power supply **208** may receive power from an external source such as an ordinary AC outlet, a portable charger, or the like. In a typical implementation, the power supply **208** also provides operating energy to other components and subsystems of the host device.

The processor **210** may be any general purpose microprocessor, controller, or microcontroller that is suitably configured to control the operation of the host device, including the wireless communication subsystem **200**. In practice, the processor **210** may execute one or more software applications or instruction sets that provide the desired functionality for the host device. In this regard, the processor **210** can control, manage, and regulate the generation and transmission of outgoing RF signals, and the receipt and handling of incoming RF signals as needed.

The memory **212** may be realized as any processor-readable medium, including an electronic circuit, a semiconductor memory device, a ROM, a flash memory, an erasable ROM, a floppy diskette, a CD-ROM, an optical disk, a hard disk, an organic memory element, or the like. For example, the memory **212** is capable of storing application software utilized by the host device and/or data utilized by the host device during operation, e.g., physiological data of the patient, device status data, control commands, configuration setting data, and the like.

In certain embodiments, the medical fluid infusion device **102** and the wireless communication subsystem **200** utilize circuit boards to mount electronic components and to implement conductive traces, signal paths, and voltage supply lines. In this regard, operating power/energy can be provided by power planes embedded in a multilayer structure of a circuit board. Such power planes can induce electromagnetic radiation in a manner that is highly analogous to the way microstrip antennas radiate RF energy. In a microstrip patch antenna and in a printed circuit board, radiation is induced by a time-varying fringing electric field at the edges of the board. It is desirable to have a low cost electromagnetic filtering technique that also reduces the size and footprint of traditional electromagnetic interference filter components.

The concept presented here utilizes the conductive ground plane of the transmission component **204** to form periodic or quasi-periodic structures with electromagnetically controllable properties and characteristics. More specifically, the transmission component **204** is suitably designed and fabricated to include sub-wavelength resonators that are configured to reduce electromagnetic interference. In this regard, the conductive ground plane is carefully fabricated to create a CSRR arrangement, which can be deployed as an alternative to microstrip stopband structures. The CSRR arrangement preferably includes a plurality of identical CSRR elements that cooperate to suppress certain RF signal frequencies, in particular, the second harmonic frequency of the RF signals of interest (which are transmitted and received by the host electronic device). For the exemplary embodiment described here, the CSRR arrangement is shaped, sized, dimensioned, and otherwise configured in accordance with the targeted pass band frequency range of 2.402 to 2.480 GHz, and in accordance with the targeted stop band frequency range of 4.804 to 4.960 GHz. It should be understood that the particular pass band and stop band frequency ranges will be dictated by the specific wireless protocol utilized by the host device. In this regard, a number of standard RF integrated circuit radios for medical device deployment use the 2.4 GHz industrial, scientific, and medical (ISM) band which implies the 4.804 to 4.960 GHz bandwidth. In practice, additional stop bands can be implemented by including multiple CSRRs of different sizes.

FIG. **3** is a perspective phantom view of a microstrip transmission component **300** having a CSRR arrangement **302** integrally formed therein, FIG. **4** is an exploded perspective view of the microstrip transmission component **300**, and FIG. **5** is a top phantom view of the microstrip transmission component **300**. The microstrip transmission component **300** is depicted in a simplified manner for clarity and ease of description. The shape, size, and topology of the microstrip transmission component **300** can vary as needed for the particular embodiment.

The microstrip transmission component **300** generally includes, without limitation: a dielectric substrate **304**; an electrically conductive signal trace **306**; and an electrically conductive ground plane **308**. For this particular embodiment, the CSRR arrangement **302** is integrally formed in the

ground plane **308**. The dielectric substrate **304** is formed from a suitable dielectric or insulating material such as, without limitation, plastic, an FR-4 circuit board material, a ceramic material, a flexible vinyl material, or the like. In some embodiments, the dielectric substrate **304** is a distinct component of the wireless communication subsystem **200**, as schematically depicted in FIG. **2**. In other embodiments, the dielectric substrate **304** can be realized as an integrated part of the housing **120**, an internal structure, or other part of the fluid infusion device **102**.

The dielectric constant of the substrate **304** can be chosen to obtain the desired electromagnetic characteristics. For example, the substrate **304** can be formed from a material having a dielectric constant within the range of about 3.0 to 12.0. In accordance with certain exemplary embodiments, the substrate **304** is formed from a thin FR-4 material having a specified dielectric constant of 4.4. The thickness (i.e., the height dimension relative to the perspective shown in FIG. **3**) of the substrate **304** can also vary from one embodiment to another, as appropriate to achieve the desired electromagnetic characteristics. The embodiment mentioned here employs an FR-4 substrate **304** having a nominal thickness of 1.0 mm.

The dielectric substrate **304** has an upper major surface **312** and a lower major surface **314** opposite the upper major surface **312** (see FIG. **4**, which depicts the signal trace **306** and the ground plane **308** separated from the dielectric substrate **304**). The electrically conductive signal trace **306** is formed overlying the upper major surface **312**, and the electrically conductive ground plane **308** is formed overlying the lower major surface **314**. For the illustrated embodiment, the signal trace **306** is formed directly on the upper major surface **312**, and the ground plane **308** is formed directly on the lower major surface **314**. The signal trace **306** and the ground plane **308** can be formed from an electrically conductive material such as, without limitation, copper, aluminum, gold, alloys thereof, or the like. In practice, the signal trace **306** and the ground plane **308** are formed from respective layers of electrically conductive material that reside on the dielectric substrate **304**. The signal trace **306** can be fabricated by the selective removal of portions of the electrically conductive material on the upper major surface **312**, e.g., by a conventional etching procedure. Likewise, the CSRR arrangement **302** can be defined by voids formed in the electrically conductive material on the lower major surface **314**. Thus, the spaces corresponding to the CSRR arrangement **302** can be fabricated by the selective removal of portions of the electrically conductive material on the lower major surface **314**, e.g., by a conventional etching procedure. Etching away the conductive material on the lower major surface **314** represents one suitable process for integrally forming the CSRR arrangement **302** in the electrically conductive ground plane **308**.

The CSRR arrangement **302** has a layout and dimensions that are tuned to cause the CSRR arrangement **302** to resonate at the second harmonic frequency of the nominal transmission frequency of the RF signals carried by the microstrip transmission component **300**. As mentioned above, the exemplary embodiment described here considers a nominal transmission frequency of 2.40 GHz, having a second harmonic frequency of 4.80 GHz. Thus, the layout and dimensions of the CSRR arrangement are tuned to cause the CSRR arrangement to suppress or filter frequencies in a band centered around 4.80 GHz.

Although not always required, the illustrated embodiment of the CSRR arrangement **302** includes a plurality of CSRR elements **320** in series with one another. The depicted embodiment includes four CSRR elements **320**, which are all identical in layout and in their dimensions. As best shown in FIG. **5** (which is a top phantom view of the microstrip transmission component **300**), the CSRR elements **320** are arranged such that they are all centered in alignment with the electrically conductive signal trace **306**. In other words, the top-down (or, equivalently, the bottom-up) projection of the signal trace **306** has a longitudinal axis that intersects the centers of the CSRR elements **320**. This arrangement is desirable to optimize the RF coupling between the signal trace and the CSRR elements **320**.

A split ring resonator (SRR) is a resonant element having a high quality factor at microwave frequencies. An SRR is fabricated from concentric electrically conductive split rings. When an SRR is excited by an external time varying magnetic field applied parallel to the ring axis, an electromotive force around the SRR is generated, which gives rise to current loops in the SRR. These current loops are closed through the distributed capacitance between the concentric rings. In this regard, an SRR behaves as an externally driven LC circuit with a resonant frequency that can be tuned by varying certain dimensions of the SRR.

By invoking the concepts of duality and complementarity, a CSRR can be derived from an SRR structure in a straightforward way. In planar technology, a CSRR can be defined as the negative of an SRR. Accordingly, a CSRR exhibits an electromagnetic behavior that is almost the dual of that of an SRR. More specifically, a negative-ε effective permittivity can be expected for any CSRR-based medium, whereas a negative-μ behavior arises in an equivalent SRR system. In other words, an SRR can be considered to be a resonant magnetic dipole that can be excited by an axial magnetic field, while a CSRR essentially behaves as an electric dipole (with the same frequency of resonance) that can be excited by an axial electric field. The latter characteristic makes a CSRR an ideal candidate for microstrip technology implementation.

Materials with negative permeability and/or negative permittivity are known as metamaterials (MTMs). The concept of MTMs plays an important role in science and technology due to the large applicability of MTMs in the development of efficient devices. MTMs are artificial structures with electromagnetic properties different from conventional materials. They are constructed to accomplish specifically desired physical properties such as negative permeability and/or negative permittivity, and/or to alter the electromagnetic response of a device for the frequency region of interest. Most metamaterials include scattering element arrays embedded in a host matrix. The scattering elements are typically identical, and the electromagnetic properties of the medium can be inferred from the properties of the unit cell (formed by one repeated element as depicted in FIG. **6**). This characteristic allows the designer to engineer the effective electromagnetic parameters of the medium by modifying the size, shape, and composition of the unit cell.

CSRRs are sub-lambda structures, i.e., their dimensions are electrically small at the resonant frequency (typically $\leq\lambda g/10$). As used here, λg is the guide wavelength in the guiding structure (e.g., microstrip) as opposed to the wavelength in free space. Due to the small electrical dimensions, a high level of miniaturization is expected when using CSRRs. Moreover, the proposed stopband arrangement described herein has the advantage of an easier and low-cost implementation in microstrip technology, because coupling between the CSRR arrangement **302** and the electrically

conductive signal trace **306** can be simply achieved by etching the CSRR elements **320** directly in the conductive ground plane **308**.

The CSRR elements **320** (and, therefore, the CSRR arrangement **302**) and/or the microstrip transmission component **300** can be tuned to resonate at the desired frequency or frequency band. More specifically, any of the following parameters can be adjusted individually or in any desired combination: the type of dielectric material (and, inherently, the dielectric constant) used for the dielectric substrate **304**; the thickness/height of the dielectric substrate **304**; the type of conductive material used for the signal trace **306**; the type of conductive material used for the ground plane **308**; the overall shape of each CSRR element **320**; the number of CSRR elements **320** deployed; the location of the CSRR elements **320** relative to the signal trace **306**; the array period used for the CSRR elements **320** (i.e., the distance between neighboring CSRR elements **320**); the width of the signal trace **306**; and certain dimensions of the CSRR elements **320**. In this regard, FIG. **6** is a plan view of an exemplary embodiment of a CSRR element **320**; FIG. **6** employs an exaggerated scale for ease of illustration.

As mentioned above, each CSRR element **320** in the CSRR arrangement **302** is identically configured as depicted in FIG. **6**. The CSRR element **320** includes an outer split ring shaped void **350** formed in the electrically conductive material **352**, and an inner split ring shaped void **354** formed in the electrically conductive material **352**. The inner split ring shaped void **354** resides in an interior space **356** defined by the outer split ring shaped void **350**, and the two split ring shaped voids **350**, **354** are concentric. The outer split ring shaped void **350** defines a gap **360**, wherein the electrically conductive material **352** fills the gap **360**. Similarly, the inner split ring shaped void **354** defines a gap **362**, wherein the electrically conductive material **352** fills the gap **362**.

FIG. **6** includes labels that indicate certain tunable dimensions of the CSRR element **320**. The labels and their corresponding dimensions are listed below:

r=innermost radius of the inner split ring shaped void **354**;

c=line width of the inner split ring shaped void **354**, which equals the line width of the outer split ring shaped void **350** for this particular embodiment;

d=line width (separation distance) between the inner split ring shaped void **354** and the outer split ring shaped void **350**;

g=distance of the gap **360** of the outer split ring shaped void, which equals the distance of the gap **362** of the inner split ring shaped void for this particular embodiment.

Any of the above dimensions can be adjusted to tune the electromagnetic performance of the CSRR arrangement **302**. Moreover, the dielectric constant of the substrate **304**, the height of the substrate **304**, the line width of the signal trace **306**, and the center-to-center distance between neighboring CSRR elements **320** (i.e., the array period) can be adjusted to tune the electromagnetic characteristics and properties of the CSRR arrangement **302**. In particular, any one or any combination of these parameters can be adjusted to influence the passband of the microstrip transmission component **300**, the stopband (resonant frequency band) of the CSRR arrangement **302**, and the like.

In accordance with certain exemplary embodiments, the dielectric substrate **304** is formed from a thin FR-4 board having a thickness of 1.0 mm, and having a dielectric constant of 4.4. For this particular embodiment: the line width of the signal trace **306** is 1.9 mm; the line widths for c, d, and g are all equal to 0.25 mm; the radius r equals 1.75 mm; and the array period equals 5.83 mm. Simulated results for a microstrip transmission component **300** having this configuration indicate a stopband (−20.0 dB rejection) of 4.60 GHz to 5.29 GHz, which encompasses the first harmonic frequency of the desired RF signals (4.80 GHz). Therefore, a wireless electronic device, such as a medical fluid infusion device, can utilize the microstrip transmission component **300** to facilitate the communication of RF signals at the nominal transmission frequency of 2.4 GHz while effectively suppressing unwanted frequency components centered around the first harmonic frequency of 4.8 GHz. Of course, the dimensions outlined above are merely exemplary, and an embodiment of the microstrip transmission component **300** can utilize a CSRR arrangement **302** having alternative specifications if so desired, especially if needed to reject or suppress a different frequency band.

While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the claimed subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

What is claimed is:

1. A medical device comprising:

a housing;

a radio frequency (RF) communication module to process RF signals associated with operation of the medical device, the RF signals having a nominal transmission frequency;

an RF antenna associated with the RF communication module, the RF antenna integrally formed with the housing;

a physically distinct microstrip transmission component coupled between the RF communication module and the RF antenna, the microstrip transmission component comprising:

a dielectric substrate having an upper major surface and a lower major surface opposite the upper major surface;

an electrically conductive signal trace formed overlying the upper major surface;

an electrically conductive ground plane formed overlying the lower major surface; and

a complementary split ring resonator (CSRR) arrangement integrally formed in the electrically conductive ground plane, and having a layout and dimensions tuned to cause the CSRR arrangement to resonate at a harmonic frequency of the nominal transmission frequency.

2. The medical device of claim **1**, wherein the CSRR arrangement comprises a plurality of CSRR elements in series and centered in alignment with the electrically conductive signal trace.

3. The medical device of claim **2**, wherein the CSRR elements are identical in layout and dimensions.

4. The medical device of claim **1**, wherein:

the RF communication module and the RF antenna accommodate RF signals having the nominal transmission frequency centered around 2.4 GHz; and

the layout and dimensions of the CSRR arrangement are tuned to cause the CSRR arrangement to resonate at a frequency centered around 4.8 GHz.

5. The medical device of claim **1**, wherein:

the electrically conductive signal trace is formed directly on the upper major surface; and

the electrically conductive ground plane is formed directly on the lower major surface.

6. The medical device of claim **1**, wherein:

the electrically conductive ground plane comprises a layer of electrically conductive material formed directly on the lower major surface; and

the CSRR arrangement is defined by voids formed in the electrically conductive material.

7. The medical device of claim **1**, wherein:

the electrically conductive ground plane comprises a layer of electrically conductive material formed directly on the lower major surface; and

the CSRR arrangement is defined by selective removal of portions of the electrically conductive material.

8. A medical fluid infusion device comprising:

a housing;

a radio frequency (RF) communication module to process RF signals associated with operation of the medical device, the RF signals having a nominal transmission frequency;

an RF antenna associated with the RF communication module, the RF antenna integrally formed with the housing;

a physically distinct microstrip transmission component coupled between the RF communication module and the RF antenna, the microstrip transmission component comprising:

a dielectric substrate having an upper major surface and a lower major surface opposite the upper major surface;

an electrically conductive signal trace formed overlying the upper major surface; and

an electrically conductive ground plane formed overlying the lower major surface; and

a complementary split ring resonator (CSRR) arrangement for the microstrip transmission component, the CSRR arrangement having a layout and dimensions tuned to cause the CSRR arrangement to suppress a harmonic frequency component of the nominal transmission frequency of the RF signals.

9. The medical fluid infusion device of claim **8**, wherein the CSRR arrangement comprises a plurality of CSRR elements in series and centered in alignment with the electrically conductive signal trace.

10. The medical fluid infusion device of claim **8**, wherein:

the electrically conductive signal trace is formed directly on the upper major surface; and

the electrically conductive ground plane is formed directly on the lower major surface.

11. The medical fluid infusion device of claim **8**, wherein the layout and dimensions of the CSRR arrangement are tuned to cause the CSRR arrangement to resonate at the harmonic frequency.

12. The medical fluid infusion device of claim **8**, wherein the CSRR arrangement is integrally formed in the electrically conductive ground plane.

13. The medical fluid infusion device of claim **12**, wherein:

the electrically conductive ground plane comprises a layer of electrically conductive material formed directly on the lower major surface; and

the CSRR arrangement is defined by voids formed in the electrically conductive material.

14. The medical fluid infusion device of claim **12**, wherein:

the electrically conductive ground plane comprises a layer of electrically conductive material formed directly on the lower major surface; and

the CSRR arrangement is defined by selective removal of portions of the electrically conductive material.

15. A medical device comprising:

a housing;

a radio frequency (RF) communication module to process RF signals associated with operation of the medical device, the RF signals having a nominal transmission frequency;

an RF antenna associated with the RF communication module, the RF antenna integrally formed with the housing;

a physically distinct microstrip transmission component coupled between the RF communication module and the RF antenna, the microstrip transmission component comprising:

a dielectric substrate having an upper major surface and a lower major surface opposite the upper major surface;

an electrically conductive signal trace formed on the upper major surface; and

a layer of electrically conductive material formed on the lower major surface, the layer of electrically conductive material comprising voids formed therein to define a complementary split ring resonator (CSRR) arrangement having a layout and dimensions tuned to cause the CSRR arrangement to resonate at a harmonic frequency of the nominal transmission frequency.

16. The medical device of claim **15**, wherein the layer of electrically conductive material serves as a ground plane for the electrically conductive signal trace.

17. The medical device of claim **15**, wherein the CSRR arrangement comprises a plurality of CSRR elements in series and centered in alignment with the electrically conductive signal trace.

18. The medical device of claim **17**, wherein the CSRR elements are identical in layout and dimensions.

19. The medical device of claim **17**, wherein each of the CSRR elements comprises:

an outer split ring shaped void formed in the electrically conductive material; and

an inner split ring shaped void formed in the electrically conductive material, the inner split ring shaped void residing in an interior space defined by the outer split ring shaped void, and the inner split ring shaped void being concentric with the outer split ring shaped void.

20. The medical device of claim **17**, wherein:

the outer split ring shaped void has a first line width;

the inner split ring shaped void has a second line width;

the outer split ring shaped void is separated from the inner split ring shaped void by a third line width; and

the first line width, the second line width, and the third line width are equal.

* * * * *